Future Improvements to Leak Rate Analyses

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NRC Leak-Rate Analysis Software

- SQUIRT, which stands for Seepage Quantification of Upsets in Reactor Tubes, was developed as part of the First International Piping Integrity Research Group (IPIRG) program.
- Several versions were developed in IPIRG program, all in DOS environment
  - Uses the basic Henry-Fauske model for two-phase flow
  - Benchmarked against available experimental data
- Updated in NRC LB-LOCA program
  - Windows environment – User friendly
  - Effects of WRS on COD predictions
  - Incorporation of PWSCC crack morphology parameters
  - Incorporation of COD dependent crack morphology model
  - All liquid and all steam models
  - Benchmarking against other leak rate codes (PICEP and LEAK-RATE)
  - Validation with recent leak-rate experiments (Ontario Hydro and Japanese)

Upcoming Improvements to SQUIRT

- ***SQUIRT will be modified in two ongoing NRC programs***
- ***MERIT – Maximizing Enhancements in Risk Informed Technology - International group program (US-NRC, Korea, Canada, UK, Sweden, EPRI)***
  - ***Objective #1 – Continued development of a probabilistic LOCA code and standardized procedures for assessment (PRO-LOCA, SQUIRT, Cracked pipe databases, material property databases)***
  - ***Objective #2 - Assessment of weld residual stresses and their impact on stress corrosion cracking.***
- ***Component Integrity***
  - ***Further investigate component integrity issues for nuclear power safety. Issues include;***
    - ***Upper head penetration J-weld flaw evaluation***
    - ***Complex crack behavior***
    - ***Piping PFM and leak-rate improvements***
    - ***DM weld/overlay assessment***
    - ***Plastic piping issues***

Scheduled Upgrades in Leak-Rate Analyses as Part of MERIT Program

- ***Ongoing upgrades to SQUIRT Code cleanup (eliminate unused features in code)***
  - ***Incorporate air fatigue crack morphology parameters***
  - ***Address convergence issues in SQUIRT4 (calculation of crack size given leak rate) module***
  - ***Update effect of WRS on COD***
  - ***Added appropriate notes and warning messages***
  - ***Beta testing***

- ***Develop database of leak-rate experiments (motif of CIRCUMCK and AXIAL_CK pipe fracture experiment databases) for validation/verification***

- ***Add transition flow model***

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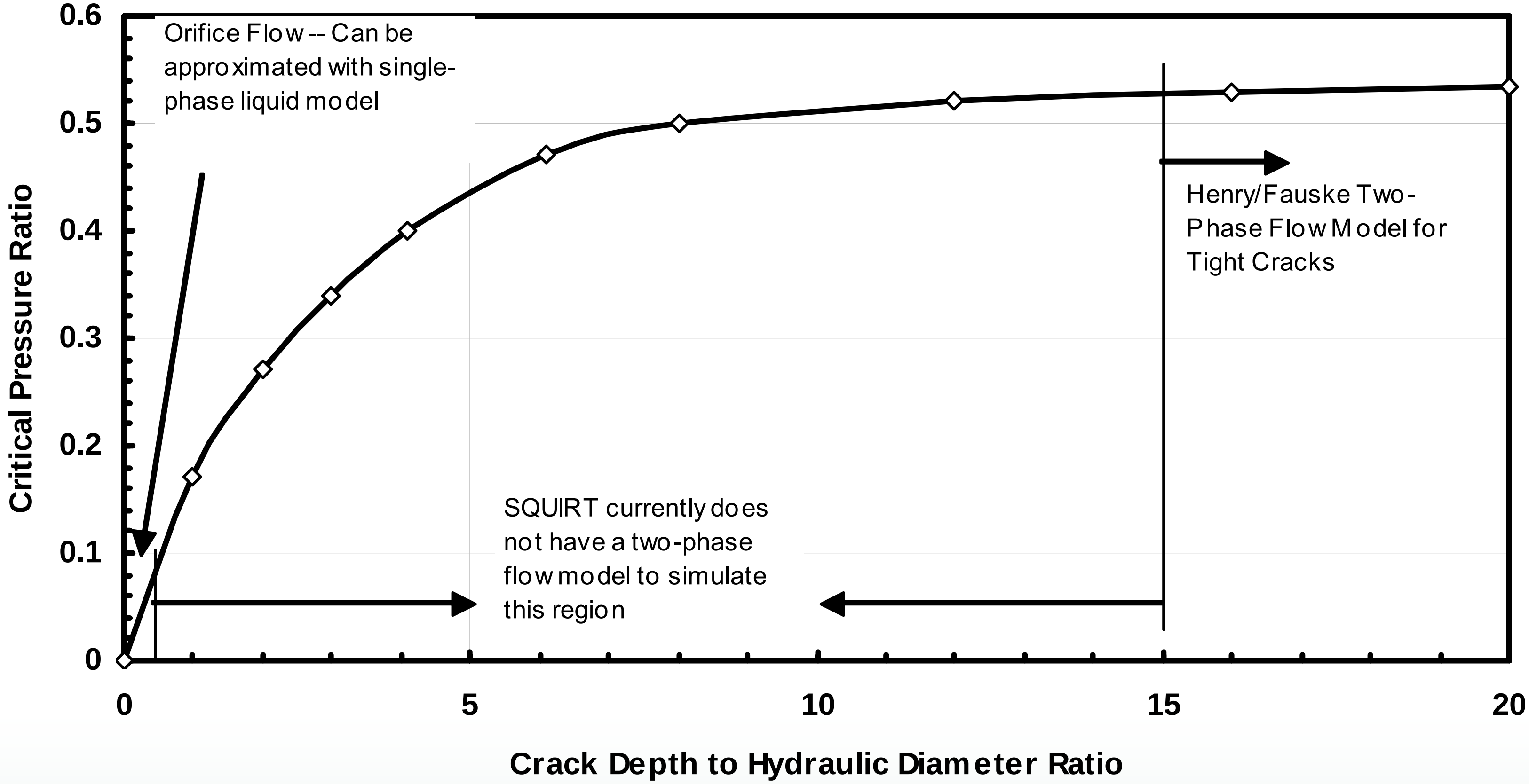
Transition Flow Model



- ***SQUIRT currently has models for both single-phase flow (d/D_h <0.5) and two-phase flow (d/D_h >15); d ~ pipe wall thickness***
- ***New model for transition flow regime (0.5 > d/D_h <15) to be developed; currently get warning message if operating in this regime***

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Scheduled Upgrades in Leak-Rate Analyses as Part of Component Integrity Program

- ***Update the current model for COD dependence on crack morphology parameters by using computational fluid dynamics***

- ***Incorporate refined IGSCC/PWSCC crack morphology parameters***
  - ***Measurements made from existing IGSCC/PWSCC micrographs***
  - ***Willing to accept any available micrographs of PWSCC cracks to add to collection!!***

- ***Resolve differences between KRAKFLO and SQUIRT***

- ***Further benchmarking and validation***

Emc^2

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Current SQUIRT COD model

- ***Crack Morphology Parameters***

Surface roughness

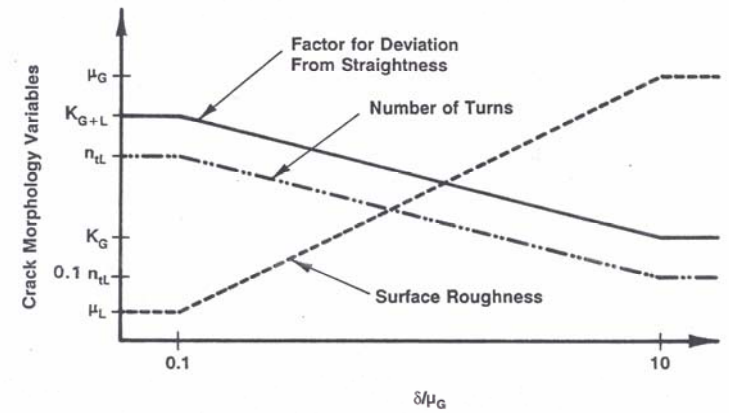
$$\mu = \begin{cases} \mu_L & 0.0 < \dfrac{\delta}{\mu_G} < 0.1 \\ \mu_L + \dfrac{\mu_G - \mu_L}{9.9}\left(\dfrac{\delta}{\mu_G - 0.1}\right), & 0.1 < \dfrac{\delta}{\mu_G} < 10 \\ \mu_G & \dfrac{\delta}{\mu_G} > 10 \end{cases}$$

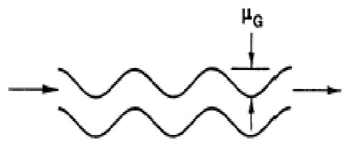
Number of turns

$$n_t = \begin{cases} n_{tL} & 0.0 < \dfrac{\delta}{\mu_G} < 0.1 \\ n_{tL} - \dfrac{n_{tL}}{11}\left(\dfrac{\delta}{\mu_G} - 0.1\right), & 0.1 < \dfrac{\delta}{\mu_G} < 10 \\ 0.1 n_{tL} & \dfrac{\delta}{\mu_G} > 10 \end{cases}$$

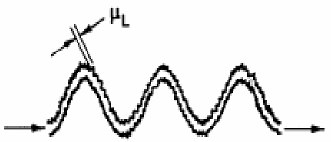
Flow path length

$$\frac{L_a}{t} = \begin{cases} K_{G+L} & 0.0 < \dfrac{\delta}{\mu_G} < 0.1 \\ K_{G+L} - \dfrac{K_{G+L} - K_G}{9.9}\left(\dfrac{\delta}{\mu_G} - 0.1\right), & 0.1 < \dfrac{\delta}{\mu_G} < 10 \\ K_G & \dfrac{\delta}{\mu_G} > 10 \end{cases}$$





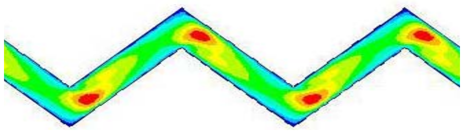
Large COD



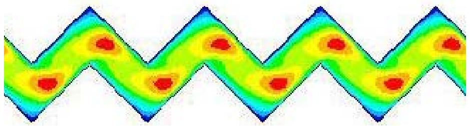
Small COD

CFD Work from Barrier Integrity Project

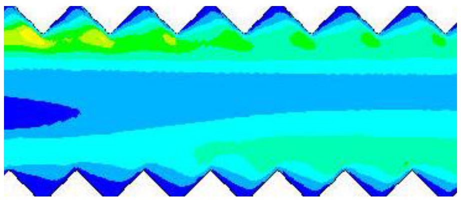
- ***An initial study using CFD with compressible flow was conducted with idealized geometry***
- ***Results suggested initial model may need to be modified***
- ***Friction coefficient is dependent on number of turns vs. straight duct segments over the length of the crack***
- ***Effect of turns seems to be eliminated by δ/μ_G= 5 (10 was used in initial SQUIRT assumptions)***
- ***Better normalizing parameter $\mu_G/(\delta - \mu_G)$?***



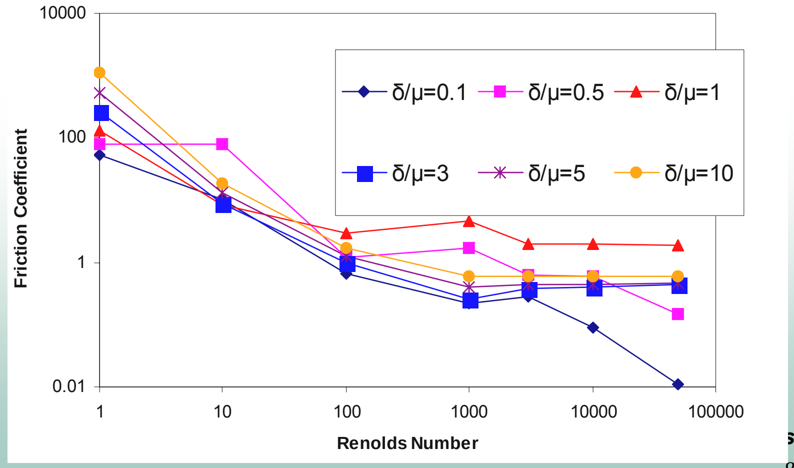
δ/μ_G=0.5



δ/μ_G=1.0



δ/μ_G=5.0

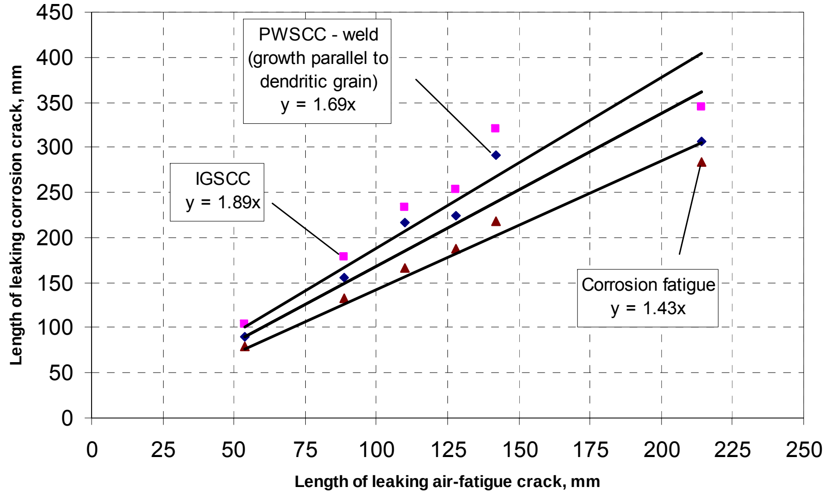


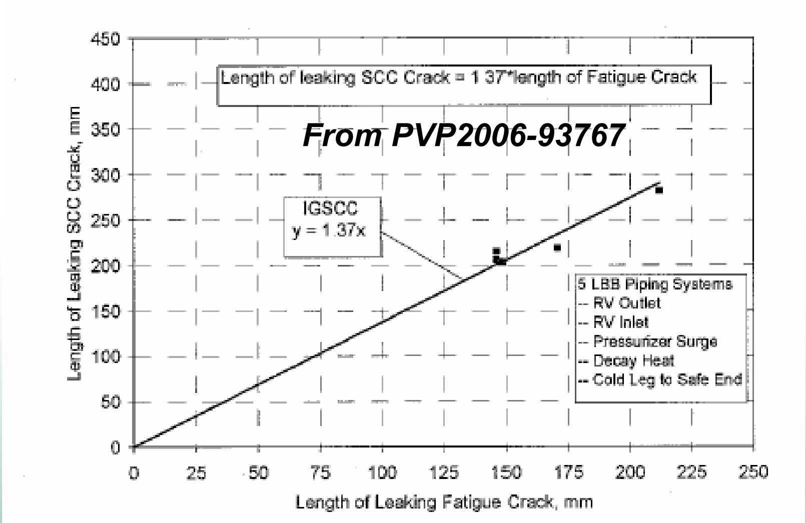
Improvement Plans – COD model

- Use CFD modeling to:
  - Investigate the effects of limiting assumptions
  - Examine the effect of offset and taper in idealized crack geometries
- Determine the most effective normalizing variable for crack morphology parameters
- Define more precisely the regime limits
  - Do all three morphology parameters need to have the same limits?
- Determine more precisely how the crack morphology parameters differ with crack type and shape
- Examining how number of turns calculated from service cracks, I.e., in the past nine 10-degree turns = one 90-degree turn, which is conservative.
  - Need CFD modeling of actual SCC flow path compared to simplified crack morphology assumptions used in SQUIRT

SQUIRT – KRAKFLO Differences

- ***From PVP2006-93767 – AREVA suggests***
  - ***KRAKFLO predicts a 37% increase for IGSCC morphology***
    - ***IGSCC morphology generated from benchmarking of Battelle Phase II experiments (200μm with 24 - 45-deg turns/inch).***
    - ***From EPRI report by Collier - Battelle used 1.78 μm with 6 – 45-deg turns in flow path for benchmark calculations.***
    - ***Emc² has a copy of another EPRI report (Project 1570-2) where the IGSCC pipe was sent for UT sizing. An attempt at making morphology measurements will be made.***
  - ***Emc² predicts a 89% increase for average IGSCC morphology***
    - ***From measurement of micrographs (not including the Collier micrographs***





SQUIRT – KRAKFLO Differences

- ***Use SQUIRT Code with COD-based improved model to benchmark against the Battelle Phase II data as well as to the available field data***
- ***Benchmarking using consistent basis for determining crack-morphology parameters for IGSCC – Does it fall in the distribution of measured morphology parameters?***
- ***Following successful benchmarking, a sensitivity study can then be performed and compared against AREVA factor of 1.37 or ~ 1.4 determined for the IGSCC morphology***

Summary

- Through two separate programs, the capabilities of the SQUIRT code will be enhanced, and further benchmarked and validated.
- Updates to the transitional flow model, the crack-morphology parameters, convergence criteria, and COD-dependence model will occur.
- Further benchmarking and validation will occur.
- Discrepancies between KRAKFLO and SQUIRT will be reconciled.